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# Polychlorinated Dibenzo-*p*-dioxins and Dibenzofurans in Fly Ash and Cinders Collected from Several Municipal Incinerators in Japan

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**Determination of polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) in fly ash and cinders collected from nine municipal incinerators in Japan was made. The concentrations of PCDDs and PCDFs in this study were generally in the same range as those in Europe and North America. However, the rather different congener composition compared with those published already were found: higher percentages of lower chlorinated (di- and tri-) dibenzo-*p*-dioxins and dibenzofurans and no or trace levels of the octachloro compounds, $O_8CDD$ and $O_8CDF$. One possible explanation for this difference may be the higher incineration temperature in Japan. The same ranges of concentrations of PCDDs and PCDFs were found in cinders as well as fly ash. The volumes of the cinders are much larger than those of fly ash and therefore the fate and impact of PCDDs and PCDFs in dump sites of these cinders should be studied.**

## Introduction

Since Olie et al. (*1*), in 1977, reported on the occurrence of PCDDs (polychlorinated dibenzo-*p*-dioxins) and PCDFs (polychlorinated dibenzofurans) in fly ash from municipal incinerators in the Netherlands, intensive studies have been conducted in Europe and North America (*2–11*). However, studies on the state-of-the-art of PCDDs and PCDFs from the municipal incinerators in Japan have not been published to date, except for two fly ash samples which had been sent to Eiceman et al. (*4*) for analysis.

This paper presents results on monitoring PCDD and PCDF residues in fly ash and cinders collected from municipal waste incinerators in Ehime Prefecture, Japan.

## Experimental

### Samples

Fly ash and cinders were sampled from nine municipal waste incinerators in seven cities in Ehime Prefecture, Japan, in 1983. The municipal incinerators are classified into three types, depending on the process of flue gas treatment: those in which the particulates and vapor in flue gases are removed by the alkaline water shower (type 1), electrostatic precipitators in cooling tower under the decreased temperature (type 2) and a combined process of above two types (type 3).

### Chemical Analysis

About 100 g of fly ash or cinders samples were employed for chemical analysis. The extraction of PCDDs and PCDFs basically followed the method of Lustenhouwer et al. (*6*), in which samples were stirred in hydrochloric acid and then extracted with toluene. The toluene extract was treated with sulfuric acid and washed with deionized water. This extract was concentrated up to 200 μL and separated into two fractions by using activated Florisil (130°C, 15 hr). The first fraction eluted with a mixed solvent of dichloromethane and hexane (1:1, v/v) containes PCDDs and PCDFs. After the second cleanup through Florisil column chromatography, the final solution containing PCDDs and PCDFs was concentrated up to 500 μL. This fraction was employed for the additional gas chromatographic cleanup by using the setup shown in Figure 1. The concentrated solution above was injected into a Chromosorb column heated at 150°C. The solvent and more

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volatile materials rapidly passed through the Chromosorb column and also a Florisil column of the aparatus shown in Fugure 1, and PCDDs and PCDFs were successfully trapped on the Florisil column. PCDDs and PCDFs collected in the Florisil column were eluted with dichloromethane (3 mL).

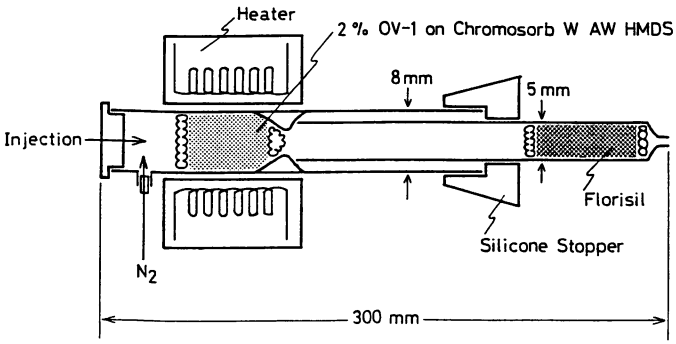


FIGURE 1. Schematic of gas chromatographic apparatus.

PCDDs and PCDFs were determined by high resolution gas chromatography medium resolution mass fragmentography. The details of GC-MS conditions were: Model: Shimadzu GC-MS 9020DF with SCAP 1123 data system; column: OV-17 (30 m length × 0.35 mm diameter); column temperature: 150°C (2 min isothermal) to 240°C, programmed at 8°C/min; EI ionization voltage: 35 eV; $M/\Delta M$: 3800 ± 100; limit of detection; 20 pg (2,3,7,8-$T_4$CDD and 2,3,7,8-$T_4$CDF). Molecular ions monitored were two highest parent ions in each isomers and congeners of di-, tri-, tetra-, penta-, hexa-, hepta-, and octachlorodibenzo-*p*-dioxins and chlorodibenzofurans. When there was disagreement of analytical values in two parent ions, another parent ion was monitored. For quantification of PCDDs and PCDFs, synthetic mixtures and pyrolyzates of PCBs were employed. Recovery of spiked PCDDs and PCDFs in fly ash for the overall analytical procedure was about 50% at the minimum.

**Table 1. Concentrations (on dry weight basis) of PCDDs in fly ash and cinders from municipal incinerators.[a]**

| Type of incinerator | City | Waste | Congeners, ng/g | | | | | | | 2,3,7,8-TCDD, ng/g | Total ng/g |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $D_2$CDD | $T_3$CDD | $T_4$CDD | $P_5$CDD | $P_6$CDD | $H_7$CDD | $O_8$CDD | | |
| 1 | A-1 | Fly ash | 4.0 | 1.2 | 10 | 6.2 | 0.9 | Tr | ND | 0.2 | 22 |
| | | Cinders | 0.5 | Tr | 1.7 | 0.4 | ND | ND | ND | 0.4 | 2.7 |
| | B | Fly ash | 32 | 5.1 | 48 | 3.5 | 0.4 | 0.2 | ND | 8.0 | 89 |
| | C | Fly ash | 4.0 | 2.6 | 12 | 1.2 | 0.2 | 3.9 | 0.2 | 0.5 | 24 |
| | | Cinders | 120 | 33 | 90 | 13 | 0.8 | 1.7 | 0.1 | 1.3 | 260 |
| 2 | D-1 | Fly ash | 200 | 82 | 250 | 310 | 6.7 | 6.7 | ND | 7.9 | 870 |
| | | Cinders | 12 | 3.9 | 92 | 3.4 | 9.0 | 0.5 | ND | 2.6 | 120 |
| | D-2 | Fly ash | 11 | 1.1 | 7.0 | 0.5 | 0.2 | Tr | ND | 0.1 | 20 |
| | E | Cinders | 1.0 | 0.4 | 3.4 | 1.3 | 0.1 | 0.5 | ND | 0.2 | 6.6 |
| 3 | F | Fly ash | 5.0 | 2.8 | 36 | 23 | 3.7 | nD | ND | 1.0 | 71 |
| | | Cinders | 1.2 | 0.4 | 4.4 | 0.4 | Tr | Tr | ND | 0.2 | 6.4 |
| | A-2 | Fly ash | 0.4 | 1.3 | 45 | 100 | 110 | 3.3 | ND | 1.6 | 260 |
| | | Cinders | 0.1 | 0.3 | 0.2 | 0.2 | Tr | Tr | ND | Tr | 0.9 |
| | G | Fly ash | 5.2 | 1.7 | 32 | 51 | 51 | 410 | 11 | 2.4 | 560 |
| | | Cinders | 1.8 | 0.2 | 26 | 0.2 | Tr | 0.6 | Tr | 6.7 | 29 |

[a]0.01< Tr< 0.1 ng/g; ND< 0.01 ng/g.

**Table 2. Concentrations (on dry weight basis) of PCDFs in fly ash and cinders from municipal incinerators.[a]**

| Type of incinerator | City | Waste | Congeners, ng/g | | | | | | | 2,3,7,8-TCDD, ng/g | Total ng/g |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $D_2$CDF | $T_3$CDF | $T_4$CDF | $P_5$CDF | $H_6$CDF | $H_7$CDF | $O_8$CDF | | |
| 1 | A-1 | Fly ash | 12 | 0.7 | 3.4 | 3.9 | 0.2 | 0.4 | ND | 0.5 | 20 |
| | | Cinders | ND | 1.1 | 0.1 | Tr | Tr | 0.6 | 0.9 | 0.4 | 2.7 |
| | B | Fly ash | 21 | 4.5 | 8.9 | 73 | 1.9 | 0.5 | ND | 1.4 | 110 |
| | C | Fly ash | 1.7 | 1.7 | 0.4 | ND | Tr | 0.7 | 0.5 | 0.5 | 4.5 |
| | | Cinders | 42 | 14 | 2.3 | 1.1 | 0.2 | 0.7 | ND | 1.3 | 60 |
| 2 | D-1 | Fly ash | 20 | 32 | 31 | 180 | 42 | 10 | 0.2 | 5.4 | 310 |
| | | Cinders | 37 | 14 | 8.4 | 12 | 2.5 | 0.8 | 0.2 | 1.2 | 74 |
| | D-2 | Fly ash | 4.0 | 1.8 | 0.9 | 12 | 0.2 | Tr | ND | 0.2 | 19 |
| | E | Cinders | 1.2 | 1.3 | 1.2 | 11 | 2.1 | 0.1 | Tr | 0.2 | 17 |
| 3 | F | Fly ash | 3.9 | 9.0 | 3.8 | 7.4 | 1.8 | 0.2 | 19 | 0.8 | 45 |
| | | Cinders | 0.7 | 0.4 | 0.2 | 0.2 | Tr | 0.3 | ND | ND | 1.8 |
| | A-2 | Fly ash | 1.8 | 8.1 | 9.9 | 2.4 | 9.9 | 3.2 | 0.4 | 2.6 | 36 |
| | | Cinders | Tr | 1.3 | 0.3 | 0.1 | ND | ND | Tr | Tr | 1.8 |
| | G | Fly ash | ND | 6.2 | 1.0 | 24 | 56 | 11 | 23 | 0.1 | 120 |
| | | Cinders | 1.3 | 1.7 | 0.2 | 0.5 | 0.1 | 0.5 | Tr | Tr | 4.3 |

[a]0.01< Tr< 0.1 ng/g; ND< 0.01 ng/g.

## Results and Discussion

The results of PCDD and PCDF analysis in fly ash and cinders collected from nine municipal incinerators in Japan are shown in Tables 1–3.

PCDDs in fly ash and cinders were found to be in the ranges of 22–870 ng/g and 0.9–260 ng/g on a dry weight basis, respectively (Table 2), where fly ash contained higher concentrations of PCDDs than cinders, except those from the incinerator for city C. In most cases, the tetrchloro ($T_4$CDD) and pentachloro ($P_5$CDD) congeners were major components in PCDDs.

The concentration levels of PCDFs (Table 2) were nearly the same as those of PCDDs in both fly ash (4.5–310 ng/g on dry weight basis) and cinders (1.8–74 ng/g on dry weight basis), and found to be higher in fly ash than in cinders.

The concentration ranges of PCDDs and PCDFs in this study are generally at the same levels as those from Europe and North America (Table 4). However, detailed congener compositions of PCDDs and PCDFs in this study showed some differences from those published already: larger percentages of lower (di- and tri-) chlorinated dibenzo-*p*-dioxins and dibenzofurans and no or trace levels of octachlorodibenzo-*p*-dioxin and octachlorodibenzofuran. The former may be explained by a systemic difference in analytical method and probably a higher incineration temperature (800–900°C) in Japan. The latter also may be explained by higher incineration temperature. This explanation is supported by the fact that the results for the city G incinerator with a poor combustion efficiency and low temperature incineration showed a larger percentage of highly chlorinated dibenzo-*p*-dioxins and dibenzofurans, including octochlorodibenzo-*p*-dioxin and octachlorodibenzofuran. City C incinerator is an old one, and the cinders there are a complicated mix of cinders, unburned waste and fly ash. Therefore, the cinders in the city C incinerator showed a peculiar distribution of PCDD and PCDF congeners.

Concentrations of 2,3,7,8-TCDD and -TCDF in Japan-

**Table 3. Percentages of 2,3,7,8-TCDD in total $T_4$CDD or PCDDs and 2,3,7,8-TCDF in total $T_4$CDF or PCDFs in fly ash and cinders.**

| Sample | Type of incinerators | City | 2,3,7,8-TCDD/total $T_4$CDD | 2,3,7,8-TCDD/PCDDs | 2,3,7,8-TCDF/total $T_4$CDF | 2,3,7,8-TCDF/PCDFs |
|---|---|---|---|---|---|---|
| Fly ash | 1 | A-1 | 1.6 | 0.7 | 15 | 2.5 |
| | | B | 17 | 9.0 | 16 | 1.3 |
| | | C | 3.8 | 1.9 | 50 | 4.2 |
| | 2 | D-1 | 3.1 | 0.9 | 17 | 1.7 |
| | | D-2 | 1.4 | 0.5 | 17 | 0.8 |
| | 3 | F | 2.7 | 1.4 | 20 | 1.7 |
| | | A-2 | 3.6 | 0.6 | 26 | 7.3 |
| | | G | 7.3 | 0.4 | 14 | 0.1 |
| | | mean | 5.1 | 1.9 | 22 | 2.5 |
| Cinders | 1 | A-1 | 20 | 13 | 25 | 0.9 |
| | | C | 1.4 | 0.5 | 15 | 0.6 |
| | 2 | D-1 | 2.8 | 2.1 | 14 | 1.6 |
| | | E | 6.2 | 3.2 | 13 | 0.9 |
| | 3 | F | 4.7 | 3.3 | —[a] | —[a] |
| | | A-2 | —[a] | —[a] | —[a] | —[a] |
| | | G | 26 | 23 | —[a] | —[a] |
| | | mean | 10 | 7.5 | 17 | 1.0 |

[a]Concentrations of 2,3,7,8-TCDD or 2,3,7,8-TCDF were ND or Tr.

**Table 4. Concentrations (ng/g on dry weight basis) of PCDDs and PCDFs in fly ash in several countries.**

| Compound | Concentrations of PCDDs and PCDFs, ng/g | | | | |
|---|---|---|---|---|---|
| | Netherlands (*6*) | Canada (*8*) | N. America (*10*) | Japan (*4*) | Japan[a] |
| $D_2$CDD | — | — | — | — | 0.4–200 |
| $T_3$CDD | — | — | — | — | 1.1–8.2 |
| $T_4$CDD | 5–110 | 3.2–27 | 2.4–85 | 4.8–8.5 | 7.0–250 |
| $P_5$CDD | 31–490 | 3.4–45 | 6.6–210 | — | 0.5–310 |
| $H_6$CDD | 80–1200 | 2.2–53 | 9.7–350 | — | 0.2–110 |
| $H_7$CDD | 190–900 | 1.1–43 | 5.7–184 | — | Tr–410 |
| $O_8$CDD | 110–270 | 0.4–26 | 2.1–35 | — | ND–11 |
| $D_2$CDF | — | — | — | — | ND–20 |
| $T_3$CDF | — | — | — | — | 0.7–32 |
| $T_4$CDF | 13–220 | — | 4.4–210 | — | 0.4–31 |
| $P_5$CDF | 42–510 | — | 18–550 | — | ND–180 |
| $H_6$CDF | 110–870 | — | 22–1100 | — | Tr–56 |
| $H_7$CDF | 89–410 | — | 11–500 | — | 0.1–11 |
| $O_8$CDF | 18–26 | — | 0.7–24 | — | ND–23 |

[a]Present study.

**Table 5. Concentrations (on dry weight basis) of PCBs in fly ash and cinders from municipal incinerators.[a]**

| Type of incinerator | City | Waste | PCB congeners, ng/g | | | | | | | Total PCBs, ng/g | Ratio PCBs/ PCDFs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $D_2CB$ | $T_3CB$ | $T_4CB$ | $P_5CB$ | $H_6CB$ | $H_7CB$ | $O_8CB$ | | |
| 1 | A-1 | Fly ash | Tr | 11 | 21 | 15 | 0.9 | ND | ND | 48 | 2.3 |
| | | Cinders | Tr | 0.2 | 0.7 | 0.4 | 0.1 | ND | ND | 1.4 | 0.5 |
| | B | Fly ash | Tr | 25 | 42 | 130 | 55 | ND | ND | 250 | 2.3 |
| | C | Fly ash | Tr | 4.1 | 1.2 | 1.5 | 5.2 | ND | ND | 12 | 2.4 |
| | | Cinders | Tr | 13 | 13 | 13 | 20 | ND | ND | 58 | 0.9 |
| 2 | D-1 | Fly ash | 2.1 | 18 | 27 | 10 | 6.5 | ND | ND | 63 | 0.2 |
| | | Cinders | 5.5 | 80 | 47 | 10 | 39 | ND | ND | 180 | 2.4 |
| | D-2 | Fly ash | 0.9 | 18 | 22 | 12 | 29 | ND | ND | 82 | 4.3 |
| | E | Cinders | Tr | 1.5 | 0.9 | 0.3 | 2.6 | ND | ND | 5.2 | 0.8 |
| 3 | F | Fly ash | 0.9 | 5.3 | 3.5 | 18 | 1.2 | ND | ND | 28 | 0.6 |
| | | Cinders | Tr | 3.7 | 6.9 | 4.5 | 10 | ND | ND | 25 | 14 |
| | A-2 | Fly ash | Tr | ND | 5.1 | 3.4 | 12 | ND | ND | 20 | 0.5 |
| | | Cinders | Tr | 0.1 | 0.1 | 0.2 | ND | ND | ND | 0.4 | 0.2 |
| | G | Fly ash | Tr | 0.1 | 0.5 | 2.4 | 6.8 | ND | ND | 9.8 | 0.1 |
| | | Cinders | Tr | 2.5 | 22 | 48 | 25 | ND | ND | 97 | 23 |

[a] 0.01< Tr< 0.1 ng/g; ND< 0.01 ng/g.

ese fly ash and cinders (Tables 1, 2 and 5) were not so different from those in Europe and North America. The highest concentrations in fly ash and cinders were 8.0 and 6.7 ng/g for 2,3,7,8-TCDD and 5.4 and 1.3 ng/g for 2,3,7,8-TCDF, respectively, both on a dry weight basis. The rather uniform ratios of 2,3,7,8-TCDF/total $T_4CDF$s suggest that the 2,3,7,8-TCDF formation during the incineration is determined by a specific process or processes and/or a specific source material. However, low concentrations of PCBs and low ratios of PCB/PCDFs in Japanese fly ash and cinders seem to indicate that PCBs may not be a main source of PCDF's from incineration facilities (Table 5).

Our finding on PCDDs and PCDFs in cinders is interesting and have never been published before to our knowledge. The volumes of the cinders are much larger than those of fly ash in municipal incinerators. In nine incinerators of this study the cinders amounted to 15 to 30% of the original wastes (wet). Consequently, the largest portion of PCDDs and PCDFs in incineration processes is contained in the cinders but not in fly ash. In Japan, disposal of these cinders has been primarily as landfill, and so we are concerned about the fate of PCDDs and PCDFs in the dump sites and their environmental and human impact.

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